



Storage tunnels keep overflows at bay

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et weather events can fill combined and sanitary sewers to capacity, discharging a mixture of stormwater runoff and sewage directly into waterways. Today, many cities are challenged to control combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) and build abatement facilities to improve water quality.

In seeking a solution, municipalities need abatement measures that will significantly reduce and eventually eliminate the volume and frequency of overflows. One option is constructing consolidation pipelines to divert CSOs and SSOs to a storage and conveyance tunnel. Overflows then can be stored until the wet weather event subsides, when excess flows are conveyed to wastewater treatment plants.

The most successful storage tunnel projects merge an integrated operation and monitoring strategy with heavy civil engineering design expertise. Project engineers must take into account a broad variety of important hydraulic, water quality, design, construction, and operating factors.

Going Deep Underground

By their nature, infrastructure projects have major impacts on communities and the environment. Construction entails traffic, noise, vibrations, dust, and the presence of heavy machinery. Cities must consider these effects before embarking on a project.

Construction of pipelines or storage basins in urban environments may be significantly affected or delayed if the contractor encounters existing underground infrastructure. Water, sewer, electric, and gas lines have an impact on routing and can increase the cost of pipeline projects. The proximity of deep pipeline excavations to building foundations and structural support systems increases project risk. Construction in and along roadways affects transportation and increases both traffic congestion and public frustration. In addition, property values, parks, and other green spaces can be compromised during and following construction.

Tunnels can help alleviate public impacts and interruptions in utility service, since they move storage and conveyance pipelines deep underground. While some surface impacts still occur, they are significantly less intrusive than those associated with open-cut pipeline alternatives. Therefore, when given a choice, stakeholders tend to select the tunneling option.

Although tunnel systems are a practical solution, they still require careful consideration during their evaluation and design in order to avoid problems in their construction and operation. Early planning also can help reduce construction cost, alleviate public concerns, and yield long-term environmental sustainability.

What's Down There?

When planning to store and convey a large volume of wastewater in a tunnel, it is important to have a clear understanding of the water quality characteristics and associated public heath issues. A study should include detailed evaluation of the geology and hydrogeology of the tunnel alignment corridor, construction and project considerations, risk management strategies, and long-term operational strategies for the tunnel system. It also is helpful to review previously completed well logs and geotechnical borings in the project area. A well-defined geotechnical program will help identify



Hydraulic and physical modeling of drop shafts facilitates smooth operation of a deep-tunnel system.

- tunnel instability hazards;
- rock hardness, strength, and permeability;
- lower rock quality that requires additional support;
- significant geologic discontinuities faults, shear zones, and solution features;
- potential for the release of hazardous and explosive gas into excavations;
- groundwater inflow potential;
- blasting-induced vibration and air-blast impacts;
- potential for soil settlement;
- · the occurrence of boulders in soils; and
- potential for ground loss during excavation caused by soil beyond the tunnel envelope or shaft footprint entering the excavation.

It is essential to have a thorough understanding of groundwater conditions and their potential impact on future construction and operation of the tunnel. The project team should use the information obtained through groundwater monitoring to develop a groundwater management program that addresses

- potential for exfiltration from the tunnel into the groundwater;
- potential groundwater quality impacts on public and private water supply wells, as well as environmental resource degradation;
- excessive groundwater infiltration during construction and potential flooding of the tunnel:
- · depletion of groundwater resources;
- excessive groundwater infiltration during operation, thereby reducing available tunnel capacity and increasing treatment costs; and
- the impact of pre-excavation grouting on existing wells.

Thinking Ahead and Managing Risk

Cities should anticipate and proactively address any potential project and construction issues in the design phase — before opportunities are missed and doors are closed. Planning for the logistics of tunnel construction and operation should parallel the evaluation of surface siting alternatives. In addition, environmental site assessments, as well as property acquisition and right-of-way studies, should be completed for planned tunnel and connection sewer alignments and potential shaft sites.

Early on in the project, cities should determine what community outreach is needed, especially regarding odor, traffic, noise, dust, and lighting concerns. Involving stakeholders in decisions about tunnel alignment and location of the working, retrieval, and drop shafts can enhance community relations.

Planning, design, and construction of a tunnel system are subject to the same risks and challenges inherent in any large underground civil project. Effective risk management and reduction require continuous assessment, mitigation, and contingency planning. A risk registry can help manage risks in the planning, preliminary engineering, design, contract, and construction phases.

A preliminary risk registry should include detailed information on technical, contractual, and socioeconomic risks. Technical risks — which are project-specific and construction-related — include cost increases; property and economic damage; failures; potential loss of life; delays; failure to attain design, operational, and quality standards; claims and disputes; and differing site conditions. Contractual risks are related to the management of geotechnical reports, design approach, and construction. Socioeconomic risks include impacts on communities, businesses, and interest groups.

Dropping and Storing Flows

A key component in using a tunnel system for storage and conveyance of wastewater flow is efficiently dropping the flow from near-surface levels to the tunnel depth. Drop shafts are used for this purpose. They transfer CSOs and SSOs from the consolidation sewers to the tunnel under controlled hydraulic conditions without damaging the overall system. A chamber may be needed at the bottom of the drop shaft to remove entrained air, convey water to the tunnel, and allow the drop shaft to withstand impact forces.

Hydraulic modeling data enable the designer to establish the flow rates at drop structures, flow characteristics within the tunnel, and the air removal requirement. Any air that is entrained along the drop shaft must be removed before it can enter the tunnel. Otherwise, it can build up, cause damage, and reduce the tunnel's storage capacity. Since air removal can result in detectable odors above ground, designers should consider odor-control measures at the drop shaft locations.

Keeping Wanted Flows in and Unwanted Flows out

Tunnel design should incorporate infiltration and exfiltration control. Typically, the maximum allowable infiltration limit for sewer systems is about 18.8 L/d per millimeter of pipe diameter per kilometer of pipe (200 gal/d per inch pipe diameter per mile of pipe). However, excessive infiltration and almost any exfiltration are not

Concrete Lining and Grouting Contact grouting is applied immediately behind liner Cutoff grouting is used in areas, post-lining grouting to reduce inflows/minimize BLACK & VEATCH exfiltration at outer tunnel

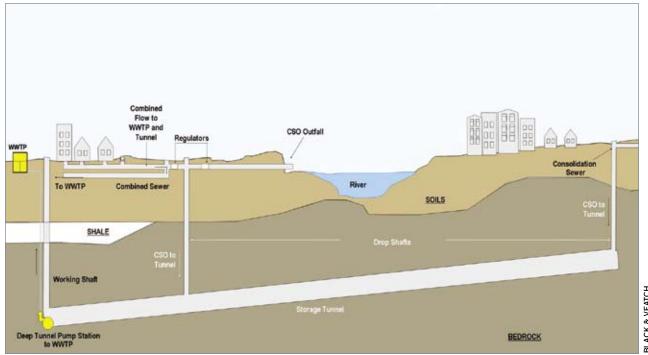
acceptable and can indicate defects and potential problems with the tunnel system design, construction, or operation.

Exfiltration merits special consideration. If it occurs, groundwater quality could be adversely affected by the addition of nutrients (such as nitrogen and phosphorus), depleted dissolved-oxygen levels, and increased suspended solids, endocrine disruptors, and pathogens (such as fecal coliforms and Escherichia coli). Everyone involved in tunnel design, construction, and operation should understand fully the fate and transport of these and other constituents if they are leaked from a tunnel into the aquifer system.

Evaluation should include the composition and parameters of the wastewater flow filling the tunnel, as well as the groundwater flow and quality characteristics of the aguifer zone where the

Cutoff grouting, contact grouting. and concrete liners can be used in large-diameter tunnels to significantly reduce infiltration and exfiltration potential.

Representation of a deep-tunnel system for collection, storage, and conveyance of combined sewer overflows from outfalls to a deep tunnel pump station for ultimate conveyance to a wastewater treatment plant.



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Joint testing of corrosion-resistant and pressure-rated carrier pipe during a tunnel replacement project in Charleston, S.C., demonstrated that the wastewater conveyance pipe was watertight and exfiltration would not occur.

tunnel is to be constructed. If the tunnel is constructed near water supply source wells, the city may have to develop a response and mitigation contingency plan. State regulations may preclude installation of a wastewater tunnel near drinking water supply wells.

Operations and Monitoring

Tunnel operation will have an impact on the degree of infiltration and exfiltration experienced. Specifically, controlling the hydraulic gradient line during operation of the tunnel system will drastically reduce the potential for exfiltration and subsequent higher infiltration rates. The designer should incorporate an inward gradient in the tunnel system so that the hydraulic grade line of flow in the tunnel does not approach or exceed the hydrostatic groundwater head in the surrounding rock. This inward gradient will decrease the likelihood of exfiltration seeping from the tunnel and also reduce the potential for higher infiltration through the same pathways once the flows have been removed.

Cities should have a groundwater monitoring program in place prior to tunnel construction. Monitoring helps establish baseline conditions of the groundwater parameters and serves as an early sentry for changed conditions. The program should continue once the tunnel is operational to help determine potential impacts on the surrounding aquifer and diagnose potential problems.

The groundwater management program should address

- identification of potential groundwater impacts and potential impacts on groundwater users,
- groundwater level monitoring,
- groundwater quality monitoring, and
- preventive and remedial measures for protection of groundwater resources.

The project team should review existing hydrogeologic information and tunnel-mapping data, and choose the most appropriate locations to install preconstruction and post-construction monitoring wells. Evaluating the data collected from the monitoring wells will help the team identify water quality problems prior to and following construction of the tunnel. The city should monitor parameters of concern periodically during tunnel operation and compare them to pre-existing conditions. A water quality model can be helpful for linking

other known water quality impairment sources to potential future problems. This can help verify that any developing impairments are from the tunnel system, rather than from other sources.

Recent Project Examples

Following are brief descriptions of three tunnel projects designed to minimize infiltration and exfiltration.

Indianapolis. The evaluation and preliminary design has been completed for the Fall Creek-White River tunnel in Indianapolis. The main spine of the tunnel will be constructed in limestone and dolomite bedrock, and could be as large as 11 m (35 ft) in diameter. The largediameter CSO storage tunnel was designed to limit infiltration and eliminate the probability of exfiltration while controlling construction costs. Concern about potential water quality impacts to public water supply wells near the tunnel alignment dictated practical and implementable controls to significantly reduce infiltration and the exfiltration potential.

Cutoff grouting, contact grouting, and cast-inplace concrete liner were evaluated to control the potential for infiltration and exfiltration from fracture and shear zones in the carbonate bedrock. Cutoff and contact grouting offer two layers of protection to prevent groundwater from entering the tunnel as infiltration and prevent wastewater from exfiltrating from the city's tunnel system. Another barrier is the construction of a cast-inplace concrete liner that could support high head pressures at the joints. Combined, the grouting plan and concrete liner offer the best protection for cost-effectively controlling infiltration and exfiltration for this large-diameter bedrock tunnel project.

Charleston, S.C. Tunneling specialists designed wastewater conveyance tunnels with corrosion potential and long-term environmental protection in mind. Wastewater carrier pipes convey flows within an oversized tunnel, and the annular space between the carrier pipe and tunnel was filled with cellular grout. A 0.8- to 1.5-m-diameter (2.5- to 5-ft-diameter) corrosion resistant pressure-rated carrier pipe was used in this 1.8-m- to 2.4-m-diameter (6- to 8-ft-diameter) tunnel application for wastewater conveyance. This conveyance system has little, if any, potential for infiltration and exfiltration.

Milwaukee. The Milwaukee Metropolitan Sewerage District's Northwest Side Relief Sewer conveyance and storage tunnel is 6 m (20 ft) in finished diameter and 11.4 km (7.1 mi) long, excavated in permeable dolomite rock at depths ranging from 40 to 55 m (130 to 180 ft) below ground. A comprehensive tunnel-water-management strategy was implemented to limit infiltration and exfiltration potential.

Groundwater inflows stabilized at approximately 9 m³/min (2300 gal/min) in the tunnel excavation prior to installation of contact grouting and concrete lining. Cutoff and contact grouting and concrete lining reduced the Northwest Side Relief Sewer tunnel groundwater inflow rate to less than 0.4 m³/min (100 gal/min) for the entire length of the tunnel. Exfiltration is negligible, because the tunnel is designed to operate under a pressure lower than the surrounding hydrostatic head at full capacity. In addition, a groundwater monitoring program has been established to monitor and mitigate any potential infiltration or exfiltration impacts on groundwater levels and groundwater quality.

The Bottom Line

For projects that encompass storage and conveyance of CSOs, SSOs, and wastewater in tunnel systems, the project team should devote special attention to strategies and controls to limit infiltration and to control exfiltration. Detailed evaluation of the geology and hydrogeology of the tunnel alignment corridor, construction and project considerations, risk management strategies, and the long-term operational strategies of the tunnel system are key not only for meeting storage and conveyance goals but also for protecting the public and the environment.

Design, construction, and operational practices to control infiltration and exfiltration should be examined carefully early in the project cycle, and project stakeholders should be involved in the process. A detailed groundwater monitoring and management plan should be developed and implemented early in the design phase of a tunnel system and periodically updated throughout design, construction, and long-term operations. Keeping the points raised in this article in mind will contribute substantially to a well-designed and constructed tunnel system that will store and convey wastewater flows with limited potential of disturbing groundwater resources.

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